Independent and combined effects of biochar and mineral fertilizers on wheat productivity and soil properties

Ayman G. Abd El-Rady [1,*], *Huda M.M. Elmasry* [2] *and Mohamed E.A. El-sayed* [2]

Address:

[1]*Wheat Research Department, Field Crops Research Institute, Agricultural Research Center, Giza 12619, Egypt*

[2]*Soils, Water and Environment Research Institute, Agriculture Research Center, Giza 12112, Egypt*

*Corresponding author: ***Ayman G. Abd-El-Rady***:ayman.gamal_1980@yahoo.com

Received: 02-03-2023; **Accpted:** 18-05-2023;**Published:** 18-05-2023 **DOI:** 10.21608/ejar.2023.197432.1378

ABSTRACT

The present study was conducted during the 2019/2020 and 2020/2021 growing seasons at Shandaweel agricultural research station, Sohag governorate to study the individual and combined effect of three rates of rice straw biochar and four rates of N, P and K mineral fertilizers on the agronomic traits, nutrient contents in leaves and grains, protein and carbohydrates content in grains of wheat cultivar Misr 3 as well as on some soil properties. The experiment design was a split plot with three replications, whereby biochar treatments occupied the main plots at a rate of 0, 5 and 10 t ha^{-1}, while the sub plots were devoted to mineral N, P and K fertilizers at a rate of 0, 50, 75 and 100% of the recommended dose. Results revealed that the combined application of 10 t ha^{-1} biochar and 100% N, P and K fertilizers treatment recorded the highest values for all the studied traits as well as improving the soil properties compared to other treatments. Furthermore, the addition of 10 t ha^{-1} biochar with 75% and 100% of N, P, and K fertilizers significantly improved grain yield by (11.13 and 18.80%) in the first season and by (7.69 and 16.62%) in the second season, respectively compared to the application of 100% of N, P and K fertilizers without biochar. In conclusion, biochar can be used to reduce using all chemical fertilizers (N, P, and K) by 25% as well as enhancing soil fertility and wheat productivity.

Keywords: Biochar, mineral fertilizers, soil quality, wheat yield

INTRODUCTION

Wheat is one of the most strategic cereal crops in Egypt, but Egypt remains the world's largest importer of wheat. In 2015, Egypt imported wheat worth 2415.47 million USD; in 2019, it cost 3024.16 million USD (Bahloul and Abdel Fatah, 2020). Wheat production in 2020/2021 in Egypt was 9.38 million tons with an average yield of 6.52 ton hectare^{-1} covering 60% of the population's needs, and it was produced from an area of 1.44 million hectares (Economic Affairs Annual report, 2021).

The combined use of chemical fertilizers plays an important role in crop growth and production. Egypt is considered to be a heavy user of chemical fertilizers, due to its intensive cropping system and raising the rate of fertilizer application for various crops (Abdel Hadi, 2004). Declining soil fertility and nutrient losses have been a foremost bane to increased crop production and food security in Egypt due to the combined effects of increasing pressure for land use for crop production and inadequate compensation of nutrients exported and lack of nutrients management as well as intensive use (Abdel Hadi, 2004). Hence, the need for soil improvement is urgent to improve its productivity and fertilizer utilization rate.

Different organic materials, e.g., sewage sludge, compost, peat, and poultry manure, have been recently used as a soil amendments (Sohi *et al.,* 2010). However, the effects of organic manure amendment on soil are short-term due to rapid decomposition, and losses through leaching and volatilization (Glaser *et al.,* 2002). Therefore, it becomes imperative to search for more stable forms of organic matter resistant to abiotic and biotic degradation for long-term effects. Recently, a lot of attention has been paid to biochar as a very promising substrate for soil remediation. Biochar is a carbon (C)-rich solid residue produced by the thermal degradation of organic materials under oxygen (O2) limited conditions for use specifically as an amendment to benefit soil (Lehmann and Joseph, 2015).

A wide range of raw materials are used as feedstock for biochar production, including wood chips, organic wastes, plant residues, and poultry manure. Rice straw is a unique feedstock for biochar production, due to the high amount of silica found in the plant tissue (Shen *et al.,* 2014). In Egypt, the processing of rice in the river Nile Delta yields large amounts of rice straw as a residue; this residue is usually burned causing air pollution and the formation of "black cloud" (El-Adly *et al.,* 2015). The conversion of rice straw into biochar and its subsequent use in agriculture seem to be an ecologically sound option for improving soil fertility and crop yield. Many studies showed that biochar application can significantly improve the content of soil organic carbon, potassium, phosphorus and calcium, which is more conducive to improving nutrient recycling, expanding nutrient capacity and reducing nutrient loss (Laird *et al.*, 2010; Li and Wei, 2016; Sachdeva *et al.,* 2019; Pokharel *et al.,* 2020).

Biochar application can improve soil health but has been widely shown to increase net microbial immobilization of inorganic N because biochar comprises C fractions with a high C:N ratio. However, because biochar contains long chain C that is not microbially available, thus biochar does not affect soil N (Phillips et al., 2022). The application of biochar to agriculture soils has many positive effects such as decreasing the phytotoxicity of heavy metals, and increasing cation exchange capacity, water-use efficiency and holding plant nutrients, along with enhancing the nutrient uptake and growth of plants (Sahin et al., 2017).

Many of the published experiments showed that biochar amendment increased wheat yield (Ibrahim *et al.,* 2019; Gupta *et al.,* 2020; Dong *et al.,* 2020). Rice straw biochar has the potential to decrease dependence on chemical fertilizers for wheat production (Iqbal, 2017). The partial application of chemical fertilizer along with rice straw biochar resulted in an improvement in wheat production as shown by an increase in wheat biomass and yield (Iqbal et al., 2019). The yield of wheat crop significantly improved through the application of biochar and various combinations of inorganic fertilizers (Ahmad *et al.,* 2016).

The combined application of biochar and chemical fertilizer had a better performance than either alone, in terms of soil properties and crop yield (Glaser *et al.,* 2015). Application of different rates of phosphorus fertilizer significantly increased plant height, number of fertile tillers per unit area, number of grains per spike, and straw and grain yield of wheat (Majeed *et al.,* 2014). Both biochar and nitrogen fertilizer application could increase wheat yield, and the effect of biochar application for increasing wheat yield was better than that of nitrogen fertilizer in medium- and low-yield farmlands (Dong et al., 2020). Biochar application significantly increased number of grains spike^{-1}, grain weight spike^{-1} and wheat grain yield (Ibrahim *et al.,* 2015). The effect of biochar was more evident in the loamy sand soil than the clay soil, suggesting the influence of biochar may be soil specific. There are few studies in the literature to demonstrate the effect of biochar application on soil physical properties under field conditions in clay loam textured soil (Ibrahim *et al.,* 2019; Hazman *et al.,* 2022)

Thus, the objective of this study was to investigate the individual and combined effect of rice straw biochar with different rates of NPK mineral fertilizers on agronomic traits, nutrient content, biochemical traits of wheat and soil properties to enhance wheat productivity and reduce chemical fertilizers addition.

MATERIALS AND METHODS

Experimental site:

A field experiment was conducted during the two growing seasons of 2019/2020 and 2020/2021 at the experimental farm of Shandaweel Agricultural Research Station, Sohag Governorate, Egypt located at 31°42´E, 26°33´N and 61 m above sea level. The same site was used during the two seasons.

Experimental design:

The wheat cultivar used in this study was Misr 3, which is a new common cultivar planted by farmers in Egypt. Sowing took place on November 25 in both seasons. The experiment was laid out in a split plot arrangement in a Randomized Complete Block Design(RCBD) with three replications. The experimental plot size was 8.4 m^2 (12 rows, 20 cm apart × 3.5 m long). The main plots were subjected to biochar treatments which were B0: no biochar was added, B1: Biochar application at 5 t ha^{-1} and B2: Biochar application at 10 t ha^{-1}. The subplots were devoted to chemical fertilization N, P and K (NPK) treatments, which were (F0): no NPK fertilizer was added; (F1): 50 %; (F2): 75% and (F3): 100% of the recommended NPK fertilizer dose.

The recommended doses for nitrogen, phosphorus and potassium according to the bulletin of the Egyptian ministry of agriculture is 178.57 kg N ha^{-1}, 35.71 kg P_2O_5 ha^{-1} and 57.14 kg K_2O ha^{-1}, in the forms of urea (46.5% N), mono superphosphate (15.5% P_2O_5) and potassium sulfate (48% K_2O), respectively. Nitrogen fertilizer was added three times; before planting irrigation (20%), before the first irrigation (40%) and before the second irrigation (40%), while phosphorus and potassium fertilizers were added before seed sowing.

The rice straw biochar was uniformly spread on the surface of the soil and was incorporated in the soil (0–30 cm depth) one week before wheat planting (Hazman *et al.,* 2022). The other agronomic practices of wheat crops were applied as recommended in the studied area. The previous crop was maize in both seasons.

Biochar preparation:

Rice straw was gathered in Egypt during the rice-harvesting season. To remove any clinging dust, the gathered straw was rinsed with tap water. After washing, the rice straw was dried in direct sunshine before being processed into a fine powder with a conventional commercial blender. The dried rice straw material was placed in tightly sealed containers to create an oxygen-limited environment during biochar production before being transferred to a pyrolysis furnace that was heated by 5 °C min^{-1} to 350 °C under anaerobic conditions and then maintained for one hour until no further smoke exhaust was produced (Reza *et al.,* 2020). After one hour, the pyrolysis furnace was allowed to cool to 40–50 °C before collecting the resultant biochar and crushed into small particulates before use. The physical and chemical properties of this biochar and soil are shown in Table 1.

Table 1: Physical and chemical properties of rice straw biochar (RSB) used in the experiment.

Item	pH	C%	H%	S%	O%	N%	K%	P%	WHC(g/g)	BET Surface Area (m^2/g)
Value	7.9	45.6	4.7	-	44.8	0.8	1.5	2.6	1.72	31.2

C%: Carbon, H%:Hydrogen, S%:Sulfur, O% Oxygen, N%: Nitrogen, K%: Potassium, P%: Phosphorus, WHC: Water-holding capacity and BET: Brunauer–Emmett–Teller theory, respectively.

Soil properties:

Soil samples were taken randomly with an auger before sowing and at harvest from (0–30 cm depth) from each experimental unit. The soil samples were air-dried, ground, well mixed and passed through a 2 mm sieve and analyzed to determine the soil chemical and physical properties Table (2).

Table 2: Physical and chemical properties of soil before planting**.**

Soil					
Item	**2019/2020**	**2020/2021**	**Item**	**2019/2020**	**2020/2021**
pH	7.80	7.80	**Soluble Cations (meq/L)**		
EC ds/m	0.21	0.22	**Ca^{2+}**	0.80	0.52
OM%	0.61	0.72	**Mg^{2+}**	0.40	0.49
Particles size distribution%			**Na^{+}**	0.75	0.79
Sand%	23.90	25.20	**K^{+}**	0.34	0.33
Silt%	38.60	39.30	**Soluble Anions (meq/L)**		
Clay%	37.50	38.50	**HCO_3^-**	1.20	0.93
Texture class	Clay loam	Clay loam	**Cl^-**	0.60	1.00
Soil water content %			**SO_4^{2-}**	0.40	0.30
SP	52.00	54.00	**Available Macro-Nutrients (ppm)**		
FC	25.44	25.58	**N**	51.00	58.00
WP	12.84	12.91	**P**	14.30	17.00
BD g/cm^3	1.43	1.48	**K**	363.33	385.00

SP: Saturation point, FC: Field capacity, WP: wilting point, BD: Bulk density, OM: Organic matter, respectively**.**

The pipette method was used to estimate particle size (Gee and Or, 2002), and the Walkey and Black approach was used to determine organic carbon (OC percent) (Nelson and Sommers, 1982). Based on Jackson, (1973), the pH was tested in a soil/water suspension (1:2.5). The EC, main cations, and anions were measured in the soil, and CaCO3 was estimated using the Black calcimeter technique (Hesse, 1971). Saturation percentage (SP), bulk density (BD), field capacity (FC), and wilting point (WP) were calculated as described by Hesse, (1971).

Wheat studied traits:

Agronomic traits:

Days to heading (day), plant height (cm), number of spikes m^{-2} (spike), number of kernels $spike^{-1}$ (kernel), 1000-kernel weight (g) and grain yield (ton ha^{-1}).

Nutrient content in wheat leaves and grains:

Wheat leaves at the age of 70 days from sowing (stage of the maximum activity of plant) were gently washed with water and dried in the oven at 70 ºC. Also, grain samples at full maturity were taken for the estimation of nutrient contents. A mixture of concentrated sulphuric acid and perchloric acid was used to digest leaves and grains (Wicks and Firminger, 1942) to determine N, P and K nutrient contents as follows:

The method of micro-kjeldahl was used to determine the total nitrogen content (A.O.A.C., 1995). In the H_2SO_4 system, phosphorus was measured by using the chlorostannous reduced molybdophosphoric blue color technique and colormetrically determined using the method introduced by Jackson (1973) and potassium was measured photometrically by using a flame photometer, as reported by Jackson (1973).

Biochemical traits:

Grain protein content % was assessed according to Lowry et al., (1951) and grain carbohydrate content % was determined by using the anthronesulphuric acid technique according to Fales (1951).

Statistical analysis:

All collected data during the two growing seasons were subjected to statistical analysis using MSTATC computer program in a split plot design. The least significant difference test (L.S.D) at 0.05 level of probability was used to test the significant differences among the means of each treatment (Steel and Torrie, 1980).

RESULTS

Agronomic traits:

Effects of rice straw biochar application:

According to the data presented in Table 3, application of rice straw biochar significantly affected days to heading (DH), plant height (PLH), number of spikes m^{-2} (NS), number of kernels $spike^{-1}$ (NKS), 1000- kernel weight (1000-KW) and grain yield (GY) in both seasons. All the studied agronomic traits showed an increasing trend with the increase in rice straw biochar application. The application of 5 t ha^{-1} biochar significantly increased DH in the second season, PLH and NS in both seasons and grain yield in the first season as compared by zero biochar addition. While, the application of 10 t ha^{-1} biochar significantly increased DH, PLH, NS, NKS, 1000-KW and GY by (2.64 and 3.18%), (4.51 and 4.57%), (9.82 and 7.84%), (16.14 and 18.40%), (14.71 and 15.43%) and (18.03 and 12.90%) when compared by no biochar treatment in the 2019/2020 and 2020/2021 seasons, respectively. Also, the addition of 10 t ha^{-1} biochar to soil significantly recorded the highest values for all the studied agronomic traits compared to 5 t ha^{-1} biochar treatment in both seasons, except DH in the first season and 1000-KW in the second season.

Effects of the NPK mineral fertilization application:

The increase in nutrient status of the soil due to N, P and K mineral fertilizers addition resulted in a highly significant increase in days to heading, plant height, number of spikes m^{-2}, number of kernels $spike^{-1}$, 1000- kernel weight and grain yield as compared to zero NPK application in both seasons, regardless of the biochar used Table (3). The highest values of the agronomic studied traits were recorded at 100% of the recommended dose of NPK with significant differences with 0, 50 and 75% of the recommended dose in both seasons, except number of spikes m^{-2}, number of kernels $spike^{-1}$ in both seasons and thousand kernel weight in 2020/2021 season. The lowest values of the agronomic traits were observed from zero NPK fertilizer treatment.

Effects of interaction between rice straw biochar and NPK mineral fertilization application:

Results in Table 4 indicated that the interaction effect between biochar and NPK mineral fertilizer rates was insignificant on days to heading and plant height, while it was significant on number of spikes m^{-2}, number of kernels $spike^{-1}$, 1000- kernel weight and grain yield in both seasons. Although the days to heading and plant height were not significantly differed as by affected by different treatments, they showed an increasing trend with the increase in biochar and NPK fertilizer application. The highest values of DH, PLH, NS, NKS, 1000-KW and GY were found with the application of 10 t ha^{-1} biochar and 100% NPK mineral fertilizers (B2 F3), while the lowest values were recorded with the application of zero biochar and NPK treatment (B0F0) in the two seasons.

NPK nutrient content in wheat leaves:

Effects of the rice straw biochar application:

Data in Table 5 revealed a significant or highly significant effect of rice straw biochar addition on wheat leaves N, P, and K content in both growing seasons at 70 days after sowing (DAS). Both 5 and 10 t ha^{-1} biochar application significantly increased the leaves N, P and K content as compared to zero biochar addition in both seasons, except leaves K content at 5 t ha^{-1} application in the second season. However, the highest leaves N, P and K concentrations were obtained at 10 t ha^{-1} biochar application in both seasons.

Effects of the NPK mineral fertilization application:

Results in Table 5 revealed highly significant effect of all NPK mineral fertilization applications on the concentrations of N, P, and K in wheat leaves as compared to zero NPK application in both growing seasons at 70 days after sowing

Table 3. Effect of biochar (B) and N, P and K chemical fertilizers (F) applications on some agronomic traits of wheat in 2019/2020 and 2020/2021 seasons.

Source of variation	Trait											
	Days to heading (day)		Plant height (cm)		Number of spikes m^{-2}		Number of kernels $spike^{-1}$		1000-kernel weight (g)		Grain yield (ton ha^{-1})	
	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 22021
Biochar rates (B)												
B_0 (0 t ha^{-1})	94.67 ± 2.06 b	91.83 ± 2.04 c	112.83± 4.47 c	107.75± 5.05 c	325.83± 33.86 c	322.17 ± 32.89 c	54.04 ± 2.60 b	52.49 ± 3.34 b	49.00 ± 4.47 b	46.72 ± 3.00 b	6.60 ± 1.13 c	6.20 ± 1.09 b
B_1 (5 t ha^{-1})	96.33 ± 1.92 ab	92.67 ± 2.19 b	115.67 ± 2.77 b	110.08± 5.02 b	343.50± 29.06 b	333.00 ± 31.88 b	56.31 ± 4.31 b	55.0 ± 3.60 b	52.15 ± 4.15 b	49.37 ± 3.87 ab	7.11 ± 1.14 b	6.44 ± 1.00 b
B_2 (10 t ha^{-1})	97.17 ± 1.85 a	94.75 ± 2.18 a	117.92± 2.71 a	112.67± 4.70 a	357.83± 18.22 a	347.42 ± 22.95 a	62.76 ± 5.88 a	62.15 ± 6.10 a	56.21 ± 3.45 a	53.93 ± 6.36 a	7.79 ± 1.37 a	7.00 ± 1.36 a
F test	*	**	**	**	**	**	**	**	*	*	**	**
LSD 0.05	**1.74**	**0.73**	**1.58**	**1.67**	**9.80**	**9.76**	**3.99**	**3.77**	**3.50**	**5.00**	**0.30**	**0.34**
NPK chemical fertilizers rates (F)												
F0 (Zero NPK)	93.56 ± 1.67 c	90.89± 1.96 d	111.33± 3.43 d	104.33 ± 3.20 d	304.33 ± 22.89 c	294.11 ± 17.31 c	52.63 ± 1.76 c	51.45 ± 3.16 c	47.61 ± 3.90 d	44.31 ± 2.63 c	5.51 ± 0.53 d	4.90 ± 0.36 d
F1 (50% NPK)	96.00 ± 1.32 b	92.22± 1.30 c	114.67± 3.32 c	108.22 ± 3.35 c	341.22 ± 23.22 b	327.78 ± 21.99 b	56.88 ± 5.52 b	55.79 ± 5.53 b	51.75 ± 4.93 c	49.54 ± 4.58 b	6.80 ± 0.63 c	6.36 ± 0.32 c
F2 (75% NPK)	96.78 ± 1.72 b	93.67± 1.94 b	116.67± 2.00 b	112.44 ± 3.05 b	356.78 ± 16.38 a	354.56 ± 13.01 a	60.04 ± 5.58 a	58.66 ± 5.76 a	54.11 ± 3.45 b	52.13 ± 4.62 a	7.93 ± 0.61 b	7.18 ± 0.52 b
F3 (100% NPK)	97.89 ± 1.27 a	95.56 ± 1.67 a	119.22± 1.86 a	115.67 ± 2.24 a	367.22 ± 8.71 a	360.33 ± 7.05 a	61.26 ± 5.39 a	60.34 ± 5.67 a	56.33 ± 2.91 a	54.04 ± 4.38 a	8.43 ± 0.69 a	7.75 ± 0.61 a
F test	**	**	**	**	**	**	**	**	**	**	**	**
LSD 0.05	**0.98**	**1.31**	**1.52**	**2.46**	**11.52**	**10.41**	**2.41**	**2.29**	**1.91**	**2.02**	**0.30**	**0.26**

Note: *and** refer to significant at $p< 0.05$, $p < 0.01$, respectively.

Table 4. Effect of interaction between biochar (B) and N, P and K chemical fertilizers (F) applications on some agronomic traits of wheat in 2019/2020 and 2020/2021 seasons.

Source of variation	Trait											
	Days to heading (day)		Plant height (cm)		Number of spikes m^{-2}		Number of kernels $spike^{-1}$		1000-kernel weight (g)		Grain yield (ton ha^{-1})	
	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021
B0F0	92.00 ± 1.00	89.33 ± 0.58	107.67 ± 2.52	101.67 ± 2.89	284.33 ± 12.90 f	280.67 ± 9.02 e	51.73 ± 1.70 f	49.14 ± 2.34 g	44.67 ± 0.97 f	43.77 ± 1.59 h	5.18 ± 0.49 h	4.55 ± 0.28 i
B0F1	94.67 ± 1.53	91.67 ± 1.15	110.67 ± 1.15	106.00 ± 1.00	313.33 ± 15.28 de	305.00 ± 8.66 cd	53.52 ± 3.32 ef	51.86 ± 3.39 fg	45.67 ± 0.77 f	44.97 ± 1.07 gh	6.01 ± 0.33 g	6.19 ± 0.39 g
B0F2	95.33 ± 1.53	92.00 ± 1.00	115.00 ± 2.00	109.33 ± 2.31	340.67 ± 16.77c	348.33 ± 11.50 a	54.99 ± 2.24 def	53.95 ± 2.43 ef	51.00 ± 2.63 e	47.98 ± 2.13 fg	7.38 ± 0.07 def	6.77 ± 0.14 ef
B0F3	96.67 ± 0.58	94.33 ± 1.53	118.00 ± 2.00	114.00 ± 1.73	365.00 ± 13.23 ab	354.67 ± 5.03a	55.91 ± 1.82 de	55.00 ± 2.92 def	54.67 ± 1.61 bcd	50.14 ± 1.89 def	7.82 ± 0.14 cd	7.28 ± 0.15 cd
B1F0	93.67 ± 1.53	90.67 ± 2.52	112.00 ± 2.00	104.33 ± 2.08	298.00 ± 12.17 ef	288.33 ± 10.41 de	52.05 ± 1.67 ef	51.86 ± 2.94 fg	45.83 ± 2.32 f	43.97 ± 1.30 h	5.36 ± 0.31 h	4.99 ± 0.27 hi
B1F1	96.67 ± 0.58	92.00 ± 1.73	115.33 ± 0.58	107.00 ± 2.00	349.67 ± 5.69 bc	324.67 ± 5.51b	53.72 ± 2.33 ef	52.82 ± 2.20 efg	53.41 ± 1.63 cde	48.72 ± 1.30 ef	7.18 ± 0.27 f	6.35 ± 0.03 fg
B1F2	97.00 ± 1.00	93.00 ± 1.00	116.67 ± 1.15	113.67 ± 2.31	361.00 ± 6.56 ab	356.67 ± 14.05 a	58.88 ± 3.19 cd	56.68 ± 2.97 de	54.00 ± 0.79 cde	51.68 ± 1.35 cde	7.72 ± 0.03 cde	6.94 ± 0.21 de
B1F3	98.00 ± 100	95.00 ± 1.00	118.67 ± 1.15	115.33 ± 0.58	365.33 ± 9.24 ab	362.33 ± 7.51 a	60.59 ± 3.03 bc	58.80 ± 1.17 cd	55.33 ± 1.91 bcd	53.12 ± 1.89 cd	8.17 ± 0.21 bc	7.48 ± 0.40 bc
B2F0	95.00 ± 1.00	92.67 ± 0.58	114.33 ± 1.53	107.00 ± 2.65	330.67 ± 9.02 cd	313.33 ± 11.55 bc	54.12 ± 1.27 ef	53.34 ± 3.50 ef	52.34 ± 1.76 de	45.19 ± 4.65 gh	6.00 ± 0.48 g	5.16 ± 0.27 h
B2F1	96.67 ± 0.58	93.00 ± 1.00	118.00 ± 1.00	111.67 ± 3.51	360.67 ± 7.02 ab	353.67 ± 7.77 a	63.41 ± 3.13 ab	62.69 ± 2.91 bc	56.17 ± 2.21 abc	54.95 ± 2.20 bc	7.20 ± 0.16 ef	6.53 ± 0.43 efg
B2F2	98.00 ± 1.73	96.00 ± 1.00	118.33 ± 1.53	114.33 ± 2.08	368.67 ± 11.02 ab	358.67 ± 16.04 a	66.24 ± 3.36 a	65.35 ± 3.42 ab	57.33 ± 3.18 ab	56.73 ± 4.61 ab	8.69 ± 0.31 b	7.84 ± 0.21 b
B2F3	99.00 ± 1.00	97.33 ± 0.58	121.00 ± 1.00	117.67 ± 2.52	371.33 ± 2.31 a	364.00 ± 6.56 a	67.29 ± 2.37 a	67.22 ± 1.10 a	59.00 ± 3.36 a	58.84 ± 3.29 a	9.29 ± 27 a	8.49 ± 0.22 a
F test	ns	ns	ns	ns	*	*	*	*	*	*	*	*
LSD 0.05	----	----	----	----	19.96	18.03	4.17	3.97	3.30	3.50	0.52	0.45

Note: * and ns refer to significant at p< 0.05andnnon-significant, respectively.

Table 5. Effect of biochar (B) and N, P and K chemical fertilizers (F) applications on NPK content (%) in wheat leaves and grains in 2019/2020 and 2020/2021 seasons.

Source of variation	Nutrient content in wheat leaves						Nutrient content in wheat grains					
	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)		Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)	
	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021
Biochar rates (B)												
B_0 (0 t ha^{-1})	2.81 ± 0.43 c	2.05 ± 0.15 b	0.25 ± 0.04 b	0.28 ± 0.09 b	3.15 ± 0.66 c	2.52 ± 0.08 b	1.24± 0.11 b	1.29± 0.06 c	0.44 ± 0.07 b	0.39 ± 0.10 c	0.21 ± 0.29	0.23 ± 0.07 b
B_1 (5 t ha^{-1})	3.13 ± 0.52 b	2.28 ± 0.20 a	0.30 ± 0.05 a	0.32 ± 0.07 a	3.49 ± 0.29 b	2.66 ± 0.06 ab	1.58 ± 0.23 a	1.58± 0.17 b	0.47 ± 0.06 a	0.44 ± 0.06 b	0.23 ± 0.22	0.29 ± 0.06 a
B_2 (10 t ha^{-1})	3.34 ± 0.55 a	2.40 ± 0.15 a	0.32 ± 0.05 a	0.34 ± 0.08 a	3.72 ± 0.29 a	2.75 ± 0.07 a	1.61± 0.34 a	1.71± 0.18 a	0.51 ± 0.06 a	0.47 ± 0.03 a	0.25 ± 0.20	0.32 ± 0.05 a
F test	**	**	*	*	**	*	**	**	*	**	ns	*
LSD 0.05	**0.16**	**0.16**	**0.04**	**0.03**	**0.11**	**0.17**	**0.10**	**0.10**	**0.04**	**0.02**	**---**	**0.05**
NPK chemical fertilizers rates (F)												
F0 (Zero NPK)	2.31 ± 0.31 c	2.03 ± 0.18 b	0.22 ± 0.02 c	0.23 ± 0.05 c	2.83 ± 0.56 c	2.38 ± 0.05 c	1.29 ± 0.10 c	1.32 ± 0.10 c	0.38 ± 0.04 d	0.34 ± 0.09 c	0.13 ± 0.22 c	0.19 ± 0.06 c
F1 (50% NPK)	3.18 ± 0.20 b	2.11 ± 0.18 b	0.30 ± 0.04 b	0.30 ± 0.04 b	3.48 ± 0.12 b	2.51 ± 0.04 b	1.42 ± 0.14 b	1.55 ± 0.18 b	0.45 ± 0.04 c	0.45 ± 0.02 b	0.23 ± 0.11 b	0.29 ± 0.06 b
F2 (75% NPK)	3.41 ± 0.29 a	2.40 ± 0.20 a	0.32 ± 0.04 a	0.35 ± 0.08 a	3.73 ± 0.18 a	2.79 ± 0.04 a	1.59 ± 0.27 a	1.61 ± 0.24 a	0.50 ± 0.02 b	0.47 ± 0.02 a	0.27 ± 0.06 a	0.32 ± 0.05 ab
F3 (100% NPK)	3.45 ± 0.31 a	2.43 ± 0.18 a	0.33 ± 0.03a	0.37 ± 0.03 a	3.78 ± 0.26 a	2.89 ± 0.04 a	1.61 ± 0.33 a	1.63 ± 0.24 a	0.56 ± 0.03 a	0.48 ± 0.02 a	0.28 ± 0.16 a	0.33 ± 0.04 a
F test	**	**	**	**	**	**	**	**	**	**	**	**
LSD 0.05	**0.24**	**0.22**	**0.02**	**0.02**	**0.12**	**0.10**	**0.08**	**0.03**	**0.05**	**0.016**	**0.03**	**0.03**

Note: *,** and ns refer to significant at $p < 0.05$, $p < 0.01$ and non-significant, respectively.

(DAS), except N content under 50% NPK rate in the second season. The highest leaves N, P and K concentrations were obtained at 100% NPK application in both seasons, and it was statistically similar with 75% NPK application in both seasons.

Effects of interaction between rice straw biochar and NPK mineral fertilization application:

Results in Table 6 indicated that the interaction between biochar and NPK mineral fertilization treatments was insignificant for NPK content in wheat leaves in both seasons, except potassium content in the first season. The highest values of wheat leaves NPK content were found in the treatment receiving 10 t ha^{-1} biochar combined with 100% NPK rate followed by 75% NPK in both seasons and they were higher than the treatment receiving 100% of recommended dose of NPK fertilizers only. While the lowest values were obtained in the control treatment (B0F0) in both seasons.

NPK nutrient content in wheat grains:

Effects of the rice straw biochar application:

From Table 5, results indicated that the gradual increase in the rate of addition of biochar led to a significant increase in the NPK content of wheat grains in both seasons, except K wheat grains content in the first season. The highest values of nitrogen were found by adding biochar at a rate 10 t ha^{-1} followed by 5 t ha^{-1} compared with the control (B0) in both seasons.

Effects of the NPK mineral fertilization application:

Increasing NPK fertilizer rates from zero to 100 % caused a highly significant increase in N, P and K concentrations in wheat grains Table (5). The highest values of NPK content in wheat grains were obtained by adding 100% followed by 75% of recommended dose of NPK fertilizers with no significant difference between them in both seasons and were significantly higher than control (F0).

Effects of interaction between rice straw biochar and NPK mineral fertilization application:

Data in Table 6 showed that the interaction between biochar treatments and N, P and K chemical fertilizers was insignificant for N and P concentration in wheat grains in the first season and K concentration in both seasons. In addition, it was significant for N and P concentration in wheat grains in the second season. Plots that received 10 or 5 t ha^{-1} biochar combined with 100, 75% and 50% of N, P and K mineral fertilizers gave significantly higher values of nitrogen content in wheat grains than plots that received 100% of the recommended dose of N fertilizer without biochar in the second season. Application of 10 t ha^{-1} Biochar combined with 100 or 75% P and K mineral fertilizers

Table 6. Effect of interaction between biochar (B) and N, P and K chemical fertilizers (F) applications on NPK- content (%) in wheat leaves and grains in 2019/2020 and 2020/2021 seasons.

Source of variation	Nutrient content in wheat leaves						Nutrient content in wheat grains					
	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)		Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)	
	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021	2019/ 2020	2020/ 2021
B0F0	2.09 ± 0.05	1.92 ± 0.07	0.20 ± 0.002	0.18 ± 0.004	2.10 ± 0.05 h	2.13 ± 0.14	1.05 ± 0.01	1.21 ± 0.001f	0.33 ± 0.01	0.23 ± 0.001 g	0.10 ± 0.05	0.12 ± 0.001
B0F1	3.03 ± 0.01	2.00 ± 0.04	0.26 ± 0.01	0.25 ± 0.03	3.37 ± 0.08 ef	2.41 ± 0.05	1.19 ± 0.05	1.31 ± 0.003e	0.42 ± 0.06	0.43 ± 0.01 de	0.21 ± 0.01	0.24 ± 0.02
B0F2	3.06 ± 0.03	2.12 ± 0.01	0.27 ± 0.01	0.33 ± 0.01	3.57 ± 0.03 cde	2.75 ± 0.06	1.36 ± 0.01	1.32 ± 0.05 e	0.42 ± 0.01	0.45 ± 0.01 cde	0.26 ± 0.01	0.27 ± 0.05
B0F3	3.06 ± 0.06	2.15 ± 0.09	0.29 ± 0.01	0.34 ± 0.01	3.58 ± 0.32 cd	2.79 ± 0.09	1.38 ± 0.01	1.34 ± 0.03 e	0.57 ± 0.02	0.46 ± 0.002 bcd	0.27 ± 0.07	0.29 ± 0.01
B1F0	2.32 ± 0.18	2.07 ± 0.04	0.22 ± 0.01	0.23 ±0.1	3.05 ± 0.03 g	2.43 ± 0.10	1.31 ± 0.01	1.31 ± 0.01 e	0.37 ± 0.03	0.35 ± 0.03 f	0.15 ± 0.04	0.21 ± 0.001
B1F1	3.14 ± 0.01	2.06 ± 0.02	0.31 ± 0.04	0.32 ± 0.001	3.47 ± 0.03 def	2.49 ± 0.08	1.51 ± 0.02	1.62 ± 0.04 c	0.45 ± 0.02	0.45 ± 0.01 cde	0.23 ± 0.01	0.30 ± 0.06
B1F2	3.46 ± 0.06	2.48 ± 0.004	0.33 ± 0.01	0.36 ± 0.01	3.67 ± 0.13 cd	2.81 ± 0.07	1.70 ± 0.21	1.70 ± 0.06 b	0.53 ± 0.05	0.47 ± 0.02 abc	0.27 ± 0.002	0.33 ± 0.04
B1F3	3.58 ± 0.09	2.50 ± 0.17	0.34 ± 0.02	0.37 0.03±	3.75 ± 0.10 bc	2.91 ± 0.07	1.73 ± 0.01	1.69 ± 0.06 b	0.54 ± 0.01	0.48 ± 0.01 ab	0.28 ± 0.02	0.34 ± 0.03
B2F0	2.54 ± 0.44	2.11 ± 0.003	0.25 ± 0.002	0.26 ± 0.04	3.33 ± 0.02f	2.58 ± 0.08	1.44 ± 0.12	1.43 ± 0.03 d	0.43 ± 0.04	0.43 ± 0.01 e	0.16 ± 0.05	0.25 ± 0.01
B2F1	3.39 ± 0.24	2.27 ± 0.12	0.33 ± 0.01	0.32 ± 0.02	3.61 ± 0.06 cd	2.62 ± 0.06	1.55 ± 0.13	1.72 ± 0.01 b	0.46 ± 0.01	0.47 ± 0.03 bc	0.25 ± 0.06	0.32 ± 0.05
B2F2	3.71 ± 0.07	2.60 ± 0.32	0.36 ± 0.03	0.38 ± 0.01	3.94 ± 0.08 ab	2.82 ± 0.05	1.72 ± 0.004	1.82 ± 0.10 a	0.56 ± 0.09	0.49 ± 0.01 ab	0.29 ± 0.07	0.35 ± 0.03
B2F3	3.73 ± 0.03	2.63 ± 0.46	0.36 ± 0.03	0.39 ± 0.01	4.01 ± 0.10 a	2.98 ± 0.25	1.73 ± 0.02	1.87 ± 0.03 a	0.58 ± 0.03	0.50 ± 0.02 a	0.31 ± 0.02	0.37 ± 0.004
F test	ns	ns	ns	ns	**	ns	ns	**	ns	**	ns	ns
LSD 0.05	---	---	---	---	0.22	---	---	0.06	---	0.03	---	---

Note: ** and ns refer to significant at $p < 0.01$ and non-significant, respectively.

gave the highest values of phosphorus and potassium content in wheat grains, followed by adding 5 t ha^{-1} combined with 100 and 75 % of P and K fertilizer in both seasons. Moreover, there were no significant differences in PK content in grains between application 100% of the recommended dose of PK fertilizer only and application of 10 or 5 t ha^{-1} biochar combined with 75% PK fertilizer in both seasons.

Biochemical traits:

Effects of the rice straw biochar application:

According to data in Table 7, increasing the biochar dose from zero to 10 t ha^{-1} significantly increased the protein and carbohydrate content in wheat grains in both seasons. Application of 10 t ha^{-1} biochar significantly increased protein content in grains as compared with application of zero or 5 t ha^{-1} biochar, and carbohydrates content as compared with application of zero biochar only in both seasons.

Effects of the NPK mineral fertilization application:

Results in Table 7 reported that application of 100% NPK significantly increased grain protein content as compared with application of zero, 50 and 75% NPK, and carbohydrates content as compared with application of zero and 50% NPK only in both seasons.

Effects of interaction between rice straw biochar and NPK mineral fertilization application:

Results in Table 7 indicated that the interaction between biochar and NPK mineral fertilization treatments significantly influenced grain protein and carbohydrate content in both seasons. The highest grain protein and carbohydrates content values were recorded in the treatment receiving 10 t ha^{-1} biochar combined with 100% NPK

Table 7. Effect of biochar (B) and N,P and K chemical fertilizers (F) applications on total protein and carbohydrates content (%) in wheat grains in 2019/2020 and 2020/2021 seasons.

Source of variation	Traits			
	Protein	Carbohydrates	Protein	Carbohydrates
	2019/2020		2020/2021	
Biochar rates (B)				
B_0 (0 t ha^{-1})	10.89 ± 1.75 c	72.13 ± 6.89 b	11.27 ± 2.11 c	72.95 ± 6.44 b
B_1 (5 t ha^{-1})	13.36 ± 2.28 b	79.54 ± 5.75 a	12.38 ± 1.97 b	80.55 ± 7.68 a
B_2 (10 t ha^{-1})	14.35 ± 2.21 a	82.16 ± 5.29 a	14.03 ± 2.23 a	82.88 ± 5.37 a
F test	**	**	**	**
LSD 0.05	**0.42**	**2.75**	**0.42**	**3.72**
NPK Chemical fertilizers rates (F)				
F0 (Zero NPK)	10.34 ± 1.00 d	69.84 ± 7.22 c	10.13 ± 1.15 d	70.29 ± 7.13 c
F1 (50% NPK)	12.01 ± 1.71 c	76.88 ± 3.28 b	11.54 ± 1.08 c	78.33 ± 5.57 b
F2 (75% NPK)	13.83 ± 2.45 b	81.58 ± 5.08 a	13.21 ± 1.89 b	82.58 ± 5.39 a
F3 (100% NPK)	15.31 ± 1.40 a	83.48 ± 4.16 a	15.35 ± 0.99 a	83.97 ± 4.43 a
Ftest	**	**	**	**
LSD 0.05	**0.60**	**2.27**	**0.40**	**3.30**
Interaction between Biochar rates (B) and NPK chemical fertilizers (F)				
B0F0	9.16± 0.60 g	61.88± 4.40 g	8.84± 0.71 g	64.34± 5.24 f
B0F1	10.13± 0.03 eg	72.89± 1.73 ef	10.47± 0.32 f	72.94± 3.64 de
B0F2	10.72± 0.60 ef	75.57± 2.55 de	11.47± 0.33 e	75.74± 1.18 cd
B0F3	13.56± 00.24 c	78.18± 1.24 d	14.29± 0.38 c	78.79± 3.43 bc
B1F0	10.54± 0.06 ef	71.33± 4.50 f	10.36± 0.36 f	69.78± 6.02 ef
B1F1	12.15± 0.27 d	79.28± 1.16 cd	11.29± 0.18 e	80.08± 3.78 bc
B1F2	14.60± 0.04 b	82.46± 0.38 bc	12.53± 0.28 d	85.91± 0.31 a
B1F3	16.16± 0.66 a	85.09± 0.61 ab	15.32± 0.36 b	86.42± 2.14 a
B2F0	11.31± 0.27 de	76.30± 2.83 de	11.19± 0.63 e	76.73± 4.88 bcd
B2F1	13.74± 1.33 bc	78.46± 1.63 d	12.87± 0.32 d	81.97± 5.35 ab
B2F2	16.17± 0.08 a	86.71± 1.38 a	15.63± 0.32 b	86.09± 3.06 a
B2F3	16.20± 0.67 a	87.19± 0.74 a	16.43± 0.39 a	86.72± 1.23 a
F test	**	**	**	**
LSD 0.05	**1.03**	**3.93**	**0.69**	**5.71**

Note: ** Significant at $p < 0.01$.

rate followed by 75% NPK with no significant difference between them in both seasons, except grain protein content in the second season. The lowest values were obtained in the control treatment (B0F0) in both seasons.

Soil properties:

Biochar characterization:

The feedstock utilized and the pyrolysis process heavily influences the characteristics of biochar (Tasim *et al.,* 2019). Table 1 summarizes the biochar characteristics. The results confirm that biochar has a high carbon (C) and oxygen (O) content while having low nitrogen (N), phosphorus (P), and potassium content (K). Furthermore, biochar has a high BET surface area and CEC, which improves nutrient and cation adsorption on its surface (Mohamed *et al.,* 2017) and the soil's water-holding capacity and porosity. Similarly, dried biochar has a water retention capacity of 1.72 g/g. Biochar's enormous relative surface area improves. The biochar has an alkaline pH and low EC (Rajkovich *et al.,* 2012).

Effects of the rice straw biochar application:

The long-term use of chemical fertilizers causes several of the potential harms to soil properties, thus, reducing the chemical fertilizers addition is the best way to preserve the properties of the soil from deterioration. Biochar enhances agricultural productivity and soil sustainability, as well as, improving the fertility/productivity of the soil and improving organic matter content. In this study, biochar is used to enhance soil properties and reduce the amount of mineral fertilizers. The results in Tables 8 & 9 investigated the impact of biochar application rates on some soil properties and nutrient availability during the two seasons. Biochar addition enhanced the soil properties and nutrient availability. Also, biochar addition rates have a significant and highly significant impact on soil properties except on pH. Furthermore, increasing biochar addition rate has a significant effect on field capacity (FC), wilting point (WP) and bulk density (BD), while has a highly significant effect on saturation point (SP), organic matter (OM), electrical conductivity (EC), major cations, major anions and nutrients availability (NPK).

Effects of the NPK mineral fertilization application:

NPK applications rate during the first season Table (8) had an insignificant impact on SP, FC, WP, BD and pH, a significant impact on HCO_3^-, Na^+, P and K and a highly significant impact on OM, EC, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+ and

Table 8. Effect of biochar (B) and N, P and K chemical fertilizers (F) applications on some soil properties after harvest in 2019/2020 season.

Source of variation	Traits																
	SP	FC	WP	BD g/cm^3	OM%	pH	EC ds/m	$HCO3^-$	Cl^-	$SO4^{2-}$	Ca^{2+}	Mg^{2+}	Na^+	K^+	N ppm	P ppm	K ppm
								meq/L									
Biochar rates (B)																	
B_0 (0 t ha^{-1})	52.00 ±1.28 c	25.46 ± 0.11 b	12.84 ± 0.35 b	1.43 ± 0.02 a	0.62 ± 0.02 c	7.85 ± 0.11	0.22 ± 0.01 c	1.30 ± 0.09 c	0.68 ± 0.06 c	0.35 ± 0.05 c	0.80 ± 0.02 c	0.42 ± 0.02 c	0.74 ± 0.03 c	0.36 ± 0.02 c	55.00 ± 4.20 c	14.78 ± 0.47 c	361.33 ± 6.07 b
B_1 (5 t ha^{-1})	54.00 ± 1.35 b	25.77 ± 0.49 ab	13.01 ± 0.09 a	1.42 ± 0.01 b	0.87 ± 0.02 b	7.93 ± 0.14	0.24 ± 0.01 b	1.52 ± 0.05 b	0.79 ± 0.03 b	0.41 ± 0.03 b	0.98 ± 0.07 b	0.46 ± 0.02 b	0.78 ± 0.03 b	0.41 ± 0.02 b	80.50 ± 4.68 b	16.58 ± 0.42 b	449.75 ± 11.86 a
B_2 (10 t ha^{-1})	57.50 ± 0.90 a	26.01 ± 0.62 a	13.05 ± 0.26 a	1.41 ± 0.02 c	1.06 ± 0.07 a	7.95 ± 0.12	0.26 ± 0.01 a	1.60 ± 0.07 a	0.85 ± 0.03 a	0.44 ± 0.02 a	1.04 ± 0.03 a	0.50 ± 0.03 a	0.82 ± 0.03 a	0.44 ± 0.01 a	86.17 ± 5.34 a	17.75 ± 0.47 a	456.75 ± 12.16 a
F test	**	*	*	*	**	ns	**	**	**	**	**	**	**	**	**	**	**
LSD 0.05	**0.87**	**0.35**	**0.14**	**0.01**	**0.04**	…..	**0.01**	**0.09**	**0.01**	**0.01**	**0.03**	**0.02**	**0.03**	**0.01**	**2.97**	**0.23**	**12.21**
NPK chemical fertilizers rates (F)																	
F0 (Zero NPK)	54.67 ± 2.35	25.69 ± 0.74	12.97 ± 0.20	1.42 ± 0.02	0.81 ± 0.15 c	7.83 ± 0.14	0.23 ± 0.02 c	1.43 ± 0.19 b	0.73 ± 0.11 c	0.40 ± 0.03 b	0.91 ± 0.10 c	0.44 ± 0.04 c	0.77 ± 0.03 b	0.39 ± 0.04 b	68.67 ± 13.69 d	16.03 ± 1.49 c	416.11 ± 40.32 b
F1 (50% NPK)	54.67 ± 2.87	25.74 ± 0.27	12.99 ± 0.40	1.42 ± 0.02	0.85 ± 0.19 b	7.90 ± 0.12	0.24 ± 0.02 bc	1.47 ± 0.14 ab	0.76 ± 0.09 b	0.38 ± 0.06 c	0.95 ± 0.12 ab	0.45 ± 0.05 bc	0.77 ± 0.05 b	0.41 ± 0.03 a	72.11 ± 14.58 c	16.23 ± 1.40 bc	421.67 ± 45.17 ab
F2 (75% NPK)	54.67 ± 2.60	25.77 ± 0.29	13.00 ± 0.16	1.42 ± 0.02	0.86 ± 0.21 ab	7.97 ± 0.14	0.24 ± 0.02 ab	1.47 ± 0.15 ab	0.79 ± 0.06 a	0.39 ± 0.06 c	0.94 ± 0.12 b	0.47 ± 0.03 ab	0.78 ± 0.05 ab	0.41 ± 0.03 a	76.11 ± 15.74 b	16.50 ± 1.25 ab	426.00 ± 50.84 a
F3 (100% NPK)	54.00 ± 2.87	25.78 ± 0.63	12.90 ± 0.27	1.42 ± 0.03	0.88 ± 0.21 a	7.93 ± 0.08	0.25 ± 0.02 a	1.52 ± 0.10 a	0.80 ± 0.07 a	0.41 ± 0.04 a	0.96 ± 0.11 a	0.47 ± 0.03 a	0.80 ± 0.05 a	0.40 ± 0.04 a	78.67 ± 14.40 a	16.70 ± 1.25 a	426.67 ± 51.01 a
F test	ns	ns	ns	ns	**	ns	**	*	**	**	**	**	*	**	**	*	*
LSD 0.05	….	….	….	…..	**0.02**	….	**0.01**	**0.06**	**0.02**	**0.01**	**0.02**	**0.01**	**0.02**	**0.01**	**2.46**	**0.46**	**8.12**

SP: Saturation point, FC: Field capacity, WP: Wilting point, BD: Bulk density, OM: Organic matter. *, ** and ns refer to P<0.05, P<0.01 and non-significant, respectively.

Table 9. Effect of biochar (B) and NPK chemical fertilizers (F) applications on some soil properties after harvest in 2020/2021 season.

Source of variation	SP	FC	WP	BD g/cm^3	OM%	pH	EC ds/m	HCO_3^- meq/L	Cl^- meq/L	SO_4^{2-} meq/L	Ca^{2+} meq/L	Mg^{2+} meq/L	Na^+ meq/L	K^+ meq/L	N ppm	P ppm	K ppm
Biochar rates (B)																	
B_0 (0 t ha^{-1})	53.75 ± 0.83 c	25.60 ± 0.11 b	12.92 ± 0.24 b	1.48 ± 0.01 a	0.74 ± 0.02 c	7.88 ± 0.14	0.22 ± 0.01 c	0.93 ± 0.02 c	1.02 ± 0.02 c	0.35 ± 0.05 c	0.56 ± 0.05 c	0.51 ± 0.02 c	0.81 ± 0.03 c	0.37 ± 0.03 c	60.75 ± 3.28 c	16.50 ± 0.99 c	386.25 ± 2.38 c
B_1 (5 t ha^{-1})	56.25 ± 1.36 b	25.83 ± 0.38 b	13.04 ± 0.08 ab	1.48 ± 0.01 a	0.92 ± 0.03 b	7.95 ± 0.18	0.27 ± 0.01 b	1.01 ± 0.02 b	1.09 ± 0.03 b	0.43 ± 0.02 b	0.60 ± 0.03 b	0.54 ± 0.01 b	0.90 ± 0.04 b	0.41 ± 0.02 b	75.00 ± 5.03 b	18.00 ± 1.15 b	425.75 ± 4.63 b
B_2 (10 t ha^{-1})	58.50 ± 1.24 a	26.21 ± 0.38 a	13.23 ± 0.21 a	1.47 ± 0.01 b	1.21 ± 0.03 a	7.93 ± 0.18	0.29 ± 0.01 a	1.09 ± 0.06 a	1.14 ± 0.04 a	0.46 ± 0.02 a	0.65 ± 0.03 a	0.58 ± 0.02 a	1.01 ± 0.02 a	0.45 ± 0.03 a	79.50 ± 5.45 a	20.75 ± 1.22 a	464.17 ± 8.58 a
F test	**	*	*	*	**	ns	**	**	**	**	**	**	**	**	**	**	**
LSD 0.05	**0.654**	**0.327**	**0.206**	**0.007**	**0.035**	…	**0.007**	**0.011**	**0.009**	**0.008**	**0.01**	**0.01**	**0.019**	**0.010**	**2.359**	**0.605**	**5.992**
NPK chemical fertilizers rates (F)																	
F0 (Zero NPK)	56.00 ± 2.12	25.86 ± 0.28	13.05 ± 0.16	1.48 ± 0.01	0.94 ± 0.20 b	7.87 ± 0.18	0.25 ± 0.03	0.98 ± 0.05 b	1.06 ± 0.05 b	0.39 ± 0.07 d	0.58 ± 0.06 b	0.53 ± 0.04 b	0.88 ± 0.09 c	0.39 ± 0.05 c	67.00 ± 7.25 d	18.67 ± 2.11 a	421.67 ± 32.57 b
F1 (50% NPK)	56.33 ± 2.74	25.89 ± 0.29	13.07 ± 0.20	1.48 ± 0.01	0.96 ± 0.21 a	7.93 ± 0.16	0.26 ± 0.03	1.01 ± 0.08 a	1.08 ± 0.06 a	0.41 ± 0.07 c	0.61 ± 0.05 a	0.54 ± 0.04 ab	0.89 ± 0.10 bc	0.41 ± 0.03 b	70.00 ± 9.08 c	17.67 ± 2.08 b	424.22 ± 33.77 ab
F2 (75% NPK)	56.33 ± 2.35	25.88 ± 0.52	13.06 ± 0.17	1.48 ± 0.01	0.95 ± 0.21 ab	7.93 ± 0.16	0.26 ± 0.03	1.02 ± 0.08 a	1.09 ± 0.06 a	0.42 ± b 0.04	0.61 ± 0.04 a	0.55 ± 0.03 a	0.91 ± 0.09 b	0.41 ± 0.03ab	73.00 ± 8.73 b	18.33 ± 2.35 ab	426.67 ± 34.39 ab
F3 (100% NPK)	56.00 ± 2.06	25.90 ± 0.52	13.07 ± 0.35	1.48 ± 0.02	0.97 ± 0.22 a	7.93 ± 0.18	0.26 ± 0.03	1.03 ± 0.09 a	1.10 ± 0.05 a	0.43 ± 0.04 a	0.61 ± 0.05 a	0.56 ± 0.03 a	0.94 ± 0.08 a	0.42 ± 0.04 a	77.00 ± 10.25 a	19.00 ± 1.94 a	429.00 ± 35.71 a
F test	ns	ns	ns	ns	*	ns	ns	**	*	**	**	*	**	**	**	*	*
LSD 0.05	**….**	**….**	**….**	**…,**	**0.020**	**….**	**…**	**0.021**	**0.026**	**0.009**	**0.012**	**0.016**	**0.020**	**0.009**	**1.75**	**0.91**	**5.25**

SP: Saturation point, FC: Field capacity, WP: wilting point, BD: Bulk density, OM: Organic matter. *, ** and ns refer to P<0.05, P<0.01 and non-significant, respectively.

N. Moreover, during the second season Table (9) NPK applications rate had an insignificant effect on SP, FC, WP, BD, pH, and EC, significant impact on OM, Cl-, Mg2+, P and K, and a highly significant impact on HCO3-, SO42-, Ca2+, Na+, K+ and N.

Effects of interaction between rice straw biochar and NPK mineral fertilization application:

Results in Tables 10 & 11 show that, the effect of interaction between biochar and NPK application was insignificant on all soil properties except with some cations and anions. Eventually, a high biochar application rate (10 t ha^{-1}) enhanced all soil properties and fixed the nutrients in soil than control or less addition (5 t ha^{-1}). Furthermore, the application of 10 t ha^{-1} biochar combined with 75% N, P, and K gave enhance in soil properties compared to application of 100% of recommended dose of NPK fertilizers without biochar in both seasons. Application of 10 t ha^{-1} biochar with 75 and 100% of NPK chemical fertilizers improves the soil chemical properties.

DISCUSSION

Biochar combined with mineral fertilizers as soil amendment benefits soil quality and crop productivity. The addition of biochar, individually or in combination, has a stimulating effect on morphological characters and yield components of wheat plants as compared with control plants (Salim, 2016). Increasing plant height by biochar addition may be due to more phosphorus availability, enhancing root growth and increasing nutrient adsorption (Hussain et al., 2006). The addition of biochar to soil significantly increased number of kernels $spike^{-1}$, grain weight $spike^{-1}$ and grain yield of wheat (Ibrahim *et al.,* 2015; Mahmoud *et al.,* 2017; Abd Elwahed *et al.,* 2019; Ibrahim *et al.,* 2019). Biochar application increased spikes m^{-2} by 6.64%, grains $spike^{-1}$ by 5.6%, thousand-grain weight by 3.73%, and grain yield by 9.96%, in comparison with no biochar application (Ali *et al.,* 2015). The significant increase of wheat agronomic traits with rice straw biochar addition than no biochar in both seasons probably caused partially by more nutrients (N, P and K) were provided by biochar Table (1). Used Rice straw biochar contained 0.8, 2.6 and 1.5% of available N, P and K, which means 80, 260, and 150 kg ha^{-1} of available N, P and K, were applied with 10 t ha^{-1} rate. The positive effects of biochar on growth, yield and its components of wheat could be attributed to the improving action of biochar on the nutrient status in the soil related to greater nutrient retention and minimizing nutrient losses (Busscher *et al.,* 2010; Githinji, 2014), which enhance plant growth and grain yield. Peng et al. (2011) and Wu et al., (2012) reported that rice straw biochar contains nutrients beneficial for plants such as nitrogen, carbon and silicon.

Significant effect of N, P, and K fertilizer levels on plant height, yield and its components was observed by Khan et al., (2012) and Shende et al. (2020). The increase in these traits in response to application of N fertilizers is probably due to the enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and rapid conversion of synthesized carbohydrates into protein and consequent to an increase in the number and size of growing cells, resulting ultimately in an increased number of tillers and grain yield (Singh and Agarwal, 2001). Phosphorus (P) also is an essential crop nutrient in the early jointing stages for enhancing grain yield and yield components (Römer and Schilling, 1986). Better growth and yield of the wheat crop have been observed with the addition of K (Singh et al., 2000).

Application of biochar either alone or in combination with farmyard manure or mineral nitrogen improved yield and yield components of wheat and soil quality (Ali et al., 2015). Biochar addition to soil generally increased yield and its attributes in the absence of mineral fertilization compared to the control treatment (B0F0). However, these increases were lower than those caused by the use of mineral fertilization compared to the control soil for 50, 75 and 100% mineral fertilization rates without biochar addition Table (4). Similar results were reported by Alburquerqueet et al. (2013) who found low responses of wheat grain yield to the sole use of biochar. Compared to B0F0 (zero biochar and NPK fertilizers) treatment, NS, NKS, 1000-KW and GY were significantly increased ($P<0.05$) under 50 and 100% NPK levels in non-amended plots as well as in amended plots with rice straw biochar Table (4). These results indicate the ability of the mixed addition of biochar with N, P and K mineral fertilizers to maintain soil fertility. Many of the investigations showed that the beneficial effects of the addition of biochar on crop production are most evident when biochar is integrated with mineral fertilizers (Ahmed *et al.,* 2016; Salim, 2016; Chaudhry *et al*., 2016).

The grain yield of wheat increased significantly with increasing N, P, and K fertilizer levels up to 100% of recommended fertilizer in amended and non-amended plots with rice straw biochar. The application of 10 t ha^{-1} biochar with 100% NPK fertilizer rate produced the highest significant increase in grain yield of wheat compared to other treatments. These results agree with Alburquerque et al. (2013), who found that at the highest mineral fertilizer rate, the addition of biochar led to about 20–30 % increase in wheat grain yield compared to the use of the mineral fertilizer alone. Furthermore, the addition of 10 t ha^{-1} biochar with 75% and 100% of N, P, and K fertilizers significantly increased grain yield by 11.13 and 18.80% in the first season and by 7.69 and 16.62% in the second season, respectively compared to the application of 100% of N, P, and K fertilizers without biochar. These

Table 10. Effect of interaction between biochar (B) and N, P and K chemical fertilizers (F) applications on some soil properties after harvest in 2019/2020 season.

Source of variation	Traits																
	SP	FC	WP	BD g/cm^3	OM%	pH	EC ds/m	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	N ppm	P ppm	K ppm
								meq/L									
B0F0	52.00 ± 1.00	25.44 ± 0.13	12.84 ± 0.25	1.43 ± 0.02	0.61 ± 0.02 e	7.80 ± 0.15	0.21 ± 0.004	1.20 ± 0.05	0.60 ± 0.02 i	0.40 ± 0.03 e	0.80 ± 0.02 d	0.40 ± 0.02	0.75 ± 0.03	0.34 ± 0.01 f	51.00 ± 2.00	14.30 ± 0.30	363.33 ± 6.11
B0F1	52.00 ± 2.00	25.46 ± 0.13	12.84 ± 0.75	1.43 ± 0.03	0.62 ± 0.03 e	7.80 ± 0.10	0.22 ± 0.002	1.30 ± 0.05	0.65 ± 0.01 h	0.31 ± 0.03 g	0.80 ± 0.02 d	0.41 ± 0.02	0.73 ± 0.03	0.38 ± 0.01 e	53.00 ± 2.00	14.60 ± 0.40	363.00 ± 6.08
B0F2	53.00 ± 1.00	25.46 ± 0.13	12.84 ± 0.16	1.43 ± 0.01	0.62 ± 0.01 e	7.90 ± 0.10	0.23 ± 0.004	1.30 ± 0.05	0.72 ± 0.02 g	0.32 ± 0.03 g	0.79 ± 0.02 d	0.44 ± 0.01	0.72 ± 0.03	0.38 ± 0.01 e	56.00 ± 2.00	15.00 ± 0.30	359.00 ± 6.56
B0F3	51.00 ± 2.00	25.47 ± 0.13	12.85 ± 0.15	1.44 ± 0.02	0.63 ± 0.02 e	7.90 ± 0.10	0.23 ± 0.007	1.40 ± 0.05	0.73 ± 0.03 fg	0.37 ± 0.03 f	0.82 ± 0.02 d	0.44 ± 0.02	0.75 ± 0.03	0.35 ± 0.01 f	60.00 ± 4.00	15.20 ± 0.40	360.00 ± 8.00
B1F0	55.00 ± 1.00	25.76 ± 1.13	13.00 ± 0.15	1.42 ± 0.01	0.86 ± 0.04 d	7.80 ± 0.20	0.23 ± 0.010	1.50 ± 0.04	0.76 ± 0.02 ef	0.38 ± 0.03 f	0.90 ± 0.02 c	0.45 ± 0.02	0.76 ± 0.01	0.39 ± 0.01 de	75.00 ± 3.00	16.20 ± 0.30	435.00 ± 4.36
B1F1	54.00 ± 2.00	25.77 ± 0.13	13.01 ± 0.01	1.42 ± 0.01	0.87 ± 0.02 d	7.90 ± 0.10	0.24 ± 0.010	1.52 ± 0.02	0.78 ± 0.02 de	0.41 ± 0.03 de	1.00 ± 0.08 b	0.45 ± 0.02	0.78 ± 0.03	0.40 ± 0.02 cde	79.00 ± 1.00	16.50 ± 0.50	447.00 ± 3.00
B1F2	53.00 ± 1.00	25.77 ± 0.13	13.01 ± 0.01	1.42 ± 0.02	0.87 ± 0.01 d	8.00 ± 0.10	0.24 ± 0.010	1.52 ± 0.10	0.81 ± 0.04 cd	0.41 ± 0.02 de	1.00 ± 0.06 b	0.46 ± 0.01	0.79 ± 0.03	0.41± 0.01 bcd	82.00 ± 3.46	16.70 ± 0.40	459.00 ± 13.00
B1F3	54.00 ± 1.00	25.79 ± 0.13	13.02 ± 0.15	1.42 ± 0.01	0.88 ± 0.02 d	8.00 ± 0.05	0.26 ± 0.010	1.54 ± 0.04	0.82 ± 0.02 bc	0.42 ± 0.03 cd	1.02 ± 0.02 ab	0.47 ± 0.02	0.80 ± 0.02	0.42 ± 0.01 abc	86.00 ± 1.00	16.90 ± 0.30	458.00 ± 3.00
B2F0	57.00 ± 1.00	25.88 ± 0.87	13.06 ± 0.20	1.41 ± 0.01	0.95 ± 0.03 c	7.90 ± 0.05	0.26 ± 0.006	1.58 ± 0.13	0.84 ± 0.01 abc	0.42 ± 0.02 cd	1.03 ± 0.02 ab	0.48 ± 0.021	0.80 ± 0.03	0.43 ± 0.01 ab	80.00 ± 4.00	17.60 ± 0.70	450.00 ± 3.00
B2F1	58.00 ± 1.00	26.00 ± 0.20	13.13 ± 0.02	1.41 ± 0.02	1.05 ± 0.03 b	8.00 ± 0.10	0.26 ± 0.006	1.60 ± 0.05	0.85 ± 0.01 ab	0.43 ± 0.03 bc	1.04 ± 0.03 a	0.50 ± 0.05	0.82 ± 0.02	0.44 ± 0.02 a	84.33 ± 1.53	17.60 ± 0.70	455.00 ± 18.03
B2F2	58.00 ± 2.00	26.07 ± 0.13	13.16 ± 0.04	1.40 ± 0.01	1.10 ± 0.03 a	8.00 ± 0.23	0.26 ± 0.004	1.60 ± 0.05	0.85 ± 0.02 ab	0.44 ± 0.03 ab	1.04 ± 0.04 a	0.50 ± 0.02	0.83 ± 0.01	0.44 ± 0.01 a	90.33 ± 3.51	17.80 ± 0.20	460.00 ± 5.00
B2F3	57.00 ± 1.00	26.09 ±1.13	12.84 ± 0.47	1.40 ± 0.04	1.12 ± 0.03 a	7.90 ± 0.05	0.27 ± 0.005	1.62 ± 0.02	0.85 ± 0.07 a	0.45 ± 0.01 a	1.05 ± 0.05 a	0.51 ± 0.01	0.84 ± 0.04	0.44 ± 0.02 a	90.00 ± 4.00	18.00 ± 0.20	462.00 ± 18.00
F test	**ns**	**ns**	**ns**	**ns**	**	**ns**	**ns**	**ns**	**	**	**	**ns**	**ns**	*	**ns**	**ns**	**ns**
LSD 0.05	**….**	**….**	**….**	**….**	**0.04**	**….**	**….**	**….**	**0.03**	**0.02**	**0.03**	**….**	**….**	**0.02**	**….**	**….**	**….**

SP: Saturation point, FC: Field capacity, WP: Wilting point, BD: Bulk density, OM: Organic matter. *, ** and ns refer to P<0.05, P<0.01 and non-significant, respectively.

Table 11. Effect of interaction between biochar (B) and N, P and K chemical fertilizers (F) applications on some soil properties after harvest in 2020/2021 season.

Source of variation	Traits																
	SP	FC	WP	BD g/cm^3	OM%	pH	EC ds/m	HCO_3^- (meq/L)	Cl^- (meq/L)	SO_4^{2-} (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Na^+ (meq/L)	K^+ (meq/L)	N ppm	P ppm	K ppm
B0F0	54.00 ± 1.00	25.58 ± 0.13	12.91 ± 0.17	1.48 ± 0.01	0.72 ± 0.02	7.80 ± 0.20	0.22 ± 0.015	0.92 ± 0.04c	1.00 ± 0.01	0.30 ± 0.04 h	0.52 ± 0.03 g	0.49 ± 0.02	0.79 ± 0.04	0.33 ± 0.02 h	58.00 ± 4.00 h	17.00 ± 0.92	385.0 ± 2.00
B0F1	53.00 ± 0.58	25.62 ± 0.13	12.93 ± 0.02	1.48 ± 0.02	0.75 ± 0.03	7.90 ± 0.10	0.22 ± 0.002	0.92 ± 0.02 c	1.01 ± 0.01	0.32 ± 0.02 g	0.57 ± 0.07 f	0.50 ± 0.01	0.79 ± 0.03	0.38 ± 0.02 g	59.00 ± 1.00 gh	16.00 ± 1.00	385.00 ± 3.00
B0F2	54.00 ± 1.00	25.60 ± 0.13	12.92 ± 0.22	1.48 ± 0.02	0.73 ± 0.02	7.90 ± 0.10	0.23 ± 0.005	0.94 ± 0.02c	1.03 ± 0.01	0.38 ± 0.03 f	0.58 ± 0.04 ef	0.52 ± 0.012	0.81 ± 0.02	0.38 ± 0.02 g	62.00 ± 2.00 fg	16.00 ± 1.00	387.00 ± 2.00
B0F3	54.00 ± 1.00	25.61 ± 0.13	12.92 ± 0.49	1.48 ± 0.01	0.74 ± 0.01	7.90 ± 0.20	0.23 ± 0.002	0.94 ± 0.02 c	1.04 ± 0.01	0.39 ± 0.02 f	0.58 ± 0.03 ef	0.53 ± 0.02	0.84 ± 0.02	0.39 ± 0.03 fg	64.00 ± 2.00 f	17.00 ± 1.00	388.00 ± 2.00
B1F0	56.00 ± 2.00	25.82 ± 0.13	13.04 ± 0.02	1.48 ± 0.01	0.91 ± 0.03	7.90 ± 0.20	0.26 ± 0.003	0.99 ± 0.02 b	1.05 ± 0.01	0.42 ± 0.03 e	0.60 ± 0.05 de	0.53 ± 0.01	0.87 ± 0.03	0.40 ± 0.03 ef	70.00 ± 2.00 e	18.00 ± 0.20	420.00 ± 2.00
B1F1	57.00 ± 1.00	25.84 ± 0.13	13.04 ± 0.18	1.48 ± 0.01	0.92 ± 0.03	8.00 ± 0.20	0.27 ± 0.003	1.00 ± 0.02 b	1.10 ± 0.02	0.44 ± 0.02 cd	0.60 ± 0.03 de	0.55 ± 0.01	0.88 ± 0.02	0.41 ± 0.02 de	72.00 ± 2.00 e	17.00 ± 1.50	425.00 ± 3.00
B1F2	56.00 ± 1.00	25.82 ± 0.13	13.04 ± 0.02	1.48 ± 0.01	0.91 ± 0.03	7.90 ± 0.20	0.28 ± 0.005	1.01 ± 0.02 b	1.10 ± 0.01	0.42 ± 0.02 e	0.61 ± 0.03 cd	0.54 ± 0.02	0.90 ± 0.02	0.41 ± 0.02 de	76.00 ± 1.00 cd	18.00 ± 1.00	428.00 ± 4.00
B1F3	56.00 ± 1.73	25.85 ± 0.87	13.05 ± 0.02	1.48 ± 0.01	0.93 ± 0.03	8.00 ± 0.20	0.28 ± 0.003	1.02 ± 0.02 b	1.10 ± 0.01	0.43 ± 0.02 de	0.60 ± 0.03 de	0.55 ± 0.01	0.95 ± 0.05	0.42 ± 0.02 cd	82.00 ± 2.00 ab	19.00 ± 1.00	430.00 ± 2.00
B2F0	58.00 ± 1.00	26.17 ± 0.13	13.21 ± 0.01	1.47 ± 0.01	1.18 ± 0.03	7.90 ± 0.20	0.28 ± 0.002	1.02 ± 0.02 b	1.12 ± 0.01	0.45 ± 0.01 bc	0.63 ± 0.03 bc	0.57 ± 0.02	0.99 ± 0.02	0.43 ± 0.03 bc	73.00 ± 1.00 de	21.00 ± 2.00	460.00 ± 3.00
B2F1	59.00 ± 2.00	26.22 ± 0.13	13.24 ± 0.24	1.47 ± 0.01	1.22 ± 0.01	7.90 ± 0.20	0.29 ± 0.005	1.10 ± 0.04 a	1.14 ± 0.01	0.46 ± 0.02 ab	0.65 ± 0.03 ab	0.58 ± 0.02	1.01 ± 0.02	0.44 ± 0.02 ab	79.00 ± 4.00 bc	20.00 ± 2.00	462.67 ± 4.16
B2F2	59.00 ± 1.00	26.21 ± 0.87	13.23 ± 0.02	1.47 ± 0.01	1.21 ± 0.01	8.00 ± 0.20	0.29 ± 0.008	1.12 ± 0.02 a	1.14 ± 0.06	0.46 ± 0.02 ab	0.64 ± 0.03 ab	0.59 ± 0.02	1.01 ± 0.01	0.45 ± 0.02 ab	81.00 ± 3.00 b	21.00 ± 1.00	465.00 ± 12.00
B2F3	58.00 ± 1.00	26.23 ± 0.13	13.25 ± 0.42	1.47 ± 0.03	1.23 ± 0.04	7.90 ± 0.20	0.29 ± 0.007	1.12 ± 0.08 a	1.15 ± 0.05	0.47 ± 0.03 a	0.66 ± 0.04 a	0.59 ± 0.01	1.02 ± 0.02	0.46 ± 0.04 a	85.00 ± 5.00 a	21.00 ± 1.00	469.00 ± 13.00
F test	ns	ns	ns	ns	ns	ns	ns	*	ns	**	**	ns	ns	*	*	ns	ns
LSD 0.05	….	….	….	….	….	….	….	**0.035**	….	**0.017**	**0.021**	….	….	**0.017**	**3.039**	….	….

SP: Saturation point, FC: Field capacity, WP: Wilting point, BD: Bulk density, OM: Organic matter. *, ** and ns refer to P<0.05, P<0.01 and non-significant, respectively.

results indicate that rice straw biochar provided about 25% NPK of the recommended fertilizers for wheat and showed the potential benefits of applying rice straw biochar for improving soil fertility and wheat yield. Consequently, biochar application can be utilized to enhance wheat grain yield and decrease the dependence on chemical fertilizers. Similar results were found by Gupta et al., (2020) who indicated that wheat grain yield at 80 kg N ha^{-1} with rice straw biochar was higher than that at the sole use of 120 kg N ha^{-1} on non- amended plots.

Biochar addition induced positive changes in soil fertility due to direct nutrient addition by biochar, an increase in adsorption of cations and a reduction in leaching losses, thereby resulting in a significant increase in N, P, and K content of wheat leaves (Spokas *et al.,* 2012). Accordingly, Gupta et al. (2020) reported an increase in wheat plant N, P and K concentrations using by addition of rice straw biochar. Significant positive correlation between soil NPK concentrations and total NPK in above-ground biomass of wheat at 60 days after sowing was reported by Gupta et al. (2020).

The high values of wheat leave NPK content in treatment that received 10 t ha^{-1} biochar combined with 75% NPK than treatment that received 100% of recommended dose of NPK fertilizers only indicate that, rice straw biochar could provide about 25% of NPK from the recommended fertilizer dose and shows the potential benefits of applying rice straw biochar for improving soil fertility and NPK content in wheat plant. Accordingly, Biederman and Harpole (2013) reported increases in plant N, P and K concentrations using a meta- analysis of data from many biochar experiments.

Biochar addition induced positive changes in soil fertility, thereby resulting in a significant increase in the N, P, and K content of wheat plants (Spokas *et al.,* 2012). The significant increase of nitrogen content in wheat grains in plots receiving 10 or 5 t ha^{-1} biochar combined with 100, 75% and 50% of N, P and K mineral fertilizers than plots receiving 100% of the recommended dose of N fertilizer without biochar may be due to the higher nutrients availability in biochar-incorporated plots which further improves plant growth and quality attributes. Biochar application considerably enhanced N concentration in wheat leaves and grain Ali et al. (2015). These results show the potential benefits of applying rice straw biochar for improving N, P and K concentrations in wheat grains.

Results in Table 7 indicated that wheat grain protein and carbohydrate content were significantly enhanced due to biochar application. Similar results were found by Ali et al. (2015) who observed a 20% improvement in wheat grain protein content in response to 25 ton ha^{-1} biochar. Khan et al. (2012) also reported that the application of 20 t ha^{-1} biochar along with 150 kg N ha^{-1} as poultry manure considerably improved wheat grain protein content by 14.57%. Increasing N application significantly increased wheat grain weight and protein content (Saeed *et al.,* 2013). A significant increase of wheat grain protein and carbohydrates content in the treatment receiving 10 t ha^{-1} biochar combined with 75% NPK fertilizer rate than in the treatment receiving 100% of the recommended dose of NPK fertilizers without biochar indicate the potential benefits of applying rice straw biochar for improving grain protein and carbohydrates content in wheat plant. These results agree with those reported by Ali at al. (2015) and Khan et al., (2022) who observed improve in wheat grain protein content in response to biochar addition.

Biochar has a high surface area and porous structure retains nutrients like nitrate, ammonium, phosphates and adsorbs nutrients on its surface leading to reduces leaching (Rajkovich *et al.,* 2012; Mohamed *et al.,* 2017). The biochar application increased the soil moisture content and improved aggregation compared to the control, which enhanced the soil physical properties such as bulk density. Furthermore, the biochar application enhances the soil properties and root zoon that effect on root architecture and enhances the wheat uptake of nutrients (El-sayed *et al.,* 2021; Singh *et al.,* 2022). The long-term intensive use of chemical fertilizer may cause soil degradation. However, biochar addition reduced the negative impact of chemical fertilizer and fixed them in soil (Xu et al., 2016).

The application of 10 t ha^{-1} biochar combined with 75% N, P, and K gave significant enhancement in some soil properties compared to application of 100% of recommended dose of NPK fertilizers without biochar in both seasons. Consequently, biochar can be used to enhance wheat production, soil properties, and reduce chemical fertilizers addition. On the other hand, an excess amount of biochar increased soil C/N ratio that may reduce the content of available soil nutrients. However, the biochar long chain is not available for microbes. Thus, biochar may not be an effect on soil N and soil microbial distribution.

Economic assessment:

Egypt, like many other countries in the world, has been facing intensive use of NPK fertilizer, with its goal of food production requirements needed for its growing population that impact soil degradation and economy. The application of biochar for environmental and agricultural systems is one viable option that can increase soil quality, enhance carbon sequestration, and reduce various agricultural residuals. Recently, El-Sayed et al. (2021) investigated the biochar application increased wheat production, and increased net profit (EGP/ha). Through this experiment, the biochar addition enhances wheat production and reduces about 25% of NPK fertilizers. Also, the potential effect of biochar remained in the soil for more than 3 years as explored by Oladele (2019) . Therefore, future studies should be directed towards finding an optimum amount of biochar for application in wheat fields for higher yield and more reducing NPK fertilizers due to expanding use of biochar.

CONCLUSION

The obtained results indicated that the application of rice straw biochar alone or in combinations with mineral fertilizers NPK confirmed its ability to improve the physical properties of the clay loam soil. As consequence, it increased crop growth, NPK nutrient content in wheat plant and wheat yield. More grain yield obtained from the soil treated with biochar than untreated soil under all NPK application rates in both seasons. Furthermore, the application of 10 t ha^{-1} biochar with 75% N, P, and K significantly improved grain yield and other studied traits as well as soil properties compared to application of 100% of N, P and K fertilizers without biochar. This practice will reduce the NPK mineral fertilizer rate currently being practiced by farmer by up to 25%. Consequently, co-application of biochar and mineral fertilizers can be a promising strategy to improve soil fertility, wheat productivity and decrease the dependence on chemical fertilizers.

REFERENCES

A.O.A.C. (1995). Official Methods of Analysis of the Association Official Analytical Chemists". 15th Ed., Washington, D.C., USA.

Abd Elwahed, M. S., Abd El-Aziz, M. E., Shaaban, E. A., & Salama, D. M. (2019). New trend to use biochar as foliar application for wheat plants (*Triticum aestivum*). *Journal of Plant Nutrition*, *42*(10), 1180-1191.

Abdel Hadi, A. H. (2004). Country report on Egyptian agriculture. In *Proceedings of the IPI workshop on Potassium and Fertigation Development in West Asia and North Africa Region. Eds: Badraoui M., Bouabid R., Aït Houssa A. Horgen, Switzerland* (pp. 58-73).

Ahmad, N., Imran, M., Marral, M. R., Mubashir, M., & Butt, B. (2016). Influence of biochar on soil quality and yield related attributes of wheat (*Triticum aestivum* L.). *J. Environ. Agric. Sci*, *7*, 68-72.

Alburquerque, J. A., Salazar, P., Barrón, V., Torrent, J., del Campillo, M. D. C., Gallardo, A., & Villar, R. (2013). Enhanced wheat yield by biochar addition under different mineral fertilization levels. *Agronomy for Sustainable Development*, *33*, 475-484.

Ali, K., Arif, M., Jan, M. T., Khan, M. J., & Jones, D. L. (2015). Integrated use of Biochar: A tool for improving soil and wheat quality of degraded soil under wheat-maiza cropping pattern. *Pakistan Journal of Botany*, *47*(1), 233-240.

Bahloul, Asmaa. M. E., & Abdel Fatah. M. O. (2020). An analytical study of wheat storage allocation in Egypt between current situation and desired outcomes. *Middle East J. Agric. Res*, *9*, 34-45.

Biederman Lori, A., Harpole, W.S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Global Change Biology Bioenergy*, 5(2), 202–214.

Busscher, W. J., Novak, J. M., Evans, D. E., Watts, D. W., Niandou, M. A. S., & Ahmedna, M. (2010). Influence of pecan biochar on physical properties of a Norfolk loamy sand. *Soil Science*, *175*(1), 10-14.

Chaudhry U.K.,Shahzad, S., Naqqash, M.N., Abdul Saboor Abbas M.S.,Saeed, F.,Yaqoob S. (2016). Integration of biochar and chemical fertilizer to enhance quality of soil and wheat crop (*Triticum aestivum* L.). *Journal of Biological&. Environmental Sciences*, 2016, 9 (1), 348-358.

Dong, L., Wang, J., Shen, M., Zhang, H., Wang, L., Li, C., & Lu, C. (2022). Biochar combined with nitrogen fertilizer affects soil properties and wheat yield in medium-low-yield farmland. *Soil Use and Management*, *38*(1), 584-595.

Economic Affairs Sector. Annual report for 2021. Egypt: Ministry of Agricultural and Land reclamation, 2021.

El-Adly, R. A., Yossef, M. A., Modather, F. H., Ismail, E. A., & Abbas, D. M. (2015). Biogrease based on biochar from rice straw and waste cooking oil. *International Journal of Advances in Pharmacy, Biology and Chemistry*, *4*(1), 91-7.

El-sayed, M. E., Hazman, M., Abd El-Rady, A. G., Almas, L., McFarland, M., Shams El Din, A., & Burian, S. (2021). Biochar reduces the adverse effect of saline water on soil properties and wheat production profitability. *Agriculture*, *11*(11), 1112.

Fales, F. (1951). The assimilation and degradation of carbohydrates by yeast cells. *Journal of Biological Chemistry*, *193*(1), 113-124.

Gee, G. W., & Or, D. (2002). 2.4 Particle-size analysis. *Methods of soil analysis: Part 4 physical methods*, *5*, 255-293.

Githinji, L. (2014). Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. *Archives of Agronomy and Soil Science*, *60*(4), 457-470.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review. *Biology and fertility of soils*, *35*, 219-230.

Glaser, B., Wiedner, K., Seelig, S., Schmidt, H. P., & Gerber, H. (2015). Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. *Agronomy for Sustainable Development*, *35*, 667-678.

Gupta, R. K., Hussain, A., Sooch, S. S., Kang, J. S., Sharma, S., & Dheri, G. S. (2020). Rice straw biochar improves soil fertility, growth, and yield of rice–wheat system on a sandy loam soil. *Experimental Agriculture*, *56*(1), 118-131.

Hazman, M. Y., El-Sayed, M. E., Kabil, F. F., Helmy, N. A., Almas, L., McFarland, M., ... & Burian, S. (2022). Effect of Biochar Application to Fertile Soil on Tomato Crop Production under Saline Irrigation Regime. *Agronomy*, *12*(7), 1596.

Hesse, P. R. (1971). A textbook of soil chemical analysis.

Hussain, N., Khan, A. Z., Akbar, H., & Akhtar, S. (2006). Growth factors and yield of maize as influenced by phosphorus and potash fertilization. *Sarhad Journal of Agriculture*, *22*(4), 579.

Ibrahim, M., Mahmoud, E., Gad, L., & Khader, A. (2019). Effects of biochar and phosphorus fertilizer rates on soil physical properties and wheat yield on clay textured soil in middle Nile Delta of Egypt. *Communications in Soil Science and Plant Analysis*, *50*(21), 2756-2766.

Ibrahim, O. M., Bakry, A. B., El Kramany, M. F., & Elewa, T. A. (2015). Evaluating the role of bio-char application under two levels of water requirements on wheat production under sandy soil conditions. *Global Journal of Advanced Resarch*, *2*(2), 411-18.

Iqbal, M. T. (2017). Utilization of biochar in improving yield of wheat in Bangladesh. *Bulgarian Journal of Soil Science*, *2*(1), 53-74.

Iqbal, M. T., Ortaş, I., Ahmed, I. A., Isik, M., & Islam, M. S. (2019). Rice straw biochar amended soil improves wheat productivity and accumulated phosphorus in grain. *Journal of Plant Nutrition*, *42*(14), 1605-1623.

Jackson, M. L. (1973). Soil chemical analysis, pentice hall of India Pvt. *Ltd., New Delhi, India*, *498*, 151-154.

Khan, M. (2012). Effect of different rates on NPK on the yield contributing traits and economics wheat in Rod Kohi area of Dera Ismail Khan division. *Sarhad Journal of Agriculture 28*(2), 159-164.

Khan, M. A., Basir, A., Fahad, S., Adnan, M., Saleem, M. H., Iqbal, A., ... & Nawaz, T. (2022). Biochar optimizes wheat quality, yield, and nitrogen acquisition in low fertile calcareous soil treated with organic and mineral nitrogen fertilizers. *Frontiers in Plant Science*, *13*, 1-13.

Laird, D., Fleming, P., Wang, B., Horton, R., & Karlen, D. (2010). Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma*, *158*(3-4), 436-442.

Lehmann, J., & Joseph, S. (2015). Biochar for environmental management: an introduction. In *Biochar for environmental management* (pp. 1-13). Routledge.

Li, Z. R., & Wei, G. L. (2016). Effect of different biochar addition on leaching loss of nitrogen and phosphorus in soil. *Ecology and Environmental Sciences*, *25*(2), 333-338.

Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. *Journal of biological chemistry*, *193*, 265-275.

Mahmoud, E. K., El-Beshbeshy, T. R., Abd El-Kader, N. E., El Shal, R., & Khalafallah, N. (2017). Biochar impacts on physical properties and wheat yield of salt affected soils. *International Journal of Research and Science Publication*, *2*(1), 1-10.

Majeed, M. A., Ahmad, R., Tahir, M., Tanveer, A., & Ahmad, M. (2014). Effect of phosphorus fertilizer sources and rates on growth and yield of wheat (*Triticum aestivum* L.). *Asian Journal of Agriculture and Biology*, *2*, 14-20.

Mohamed, B. A., Ellis, N., Kim, C. S., & Bi, X. (2017). The role of tailored biochar in increasing plant growth, and reducing bioavailability, phytotoxicity, and uptake of heavy metals in contaminated soil. *Environmental Pollution*, *230*, 329-338.

Nelson, D. A., & Sommers, L. (1983). Total carbon, organic carbon, and organic matter. *Methods of soil analysis: Part 2 chemical and microbiological properties*, *9*, 539-579.

Oladele, S. O. (2019). Changes in physicochemical properties and quality index of an Alfisol after three years of rice husk biochar amendment in rainfed rice–Maize cropping sequence. *Geoderma*, *353*, 359-371.

Peng, X. Y. L. L., Ye, L. L., Wang, C. H., Zhou, H., & Sun, B. (2011). Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. *Soil and tillage research*, *112*(2), 159-166.

Phillips, C. L., Meyer, K. M., Garcia-Jaramillo, M., Weidman, C. S., Stewart, C. E., Wanzek, T., ... & Trippe, K. M. (2022). Towards predicting biochar impacts on plant-available soil nitrogen content. *Biochar*, *4*(1), 1-15.

Pokharel, P., Ma, Z., & Chang, S. X. (2020). Biochar increases soil microbial biomass with changes in extra-and intracellular enzyme activities: a global meta-analysis. *Biochar*, *2*, 65-79.

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A. R., & Lehmann, J. (2012). Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils*, *48*, 271-284.

Reza, M. S., Afroze, S., Bakar, M. S., Saidur, R., Aslfattahi, N., Taweekun, J., & Azad, A. K. (2020). Biochar characterization of invasive *Pennisetum purpureum* grass: effect of pyrolysis temperature. *Biochar*, *2*, 239-251.

Römer, W., & Schilling, G. (1986). Phosphorus requirements of the wheat plant in various stages of its life cycle. *Plant and soil*, *91*, 221-229.

Sachdeva, V., Hussain, N., Husk, B. R., & Whalen, J. K. (2019). Biochar-induced soil stability influences phosphorus retention in a temperate agricultural soil. *Geoderma*, *351*, 71-75.

Saeed, B., Khan, A. Z., Khalil, S. K., Rahman, H. U., Ullah, F., Gul, H., & Akbar, H. (2013). Response of soil and foliar applied nitrogen and sulfur towards yield and yield attributes of wheat cultivars. *Pak. J. Bot*, *45*(2), 435-442.

Sahin, O., Taskin, M. B., Kaya, E. C., Atakol, O. R. H. A. N., Emir, E., Inal, A., & Gunes, A. Y. D. I. N. (2017). Effect of acid modification of biochar on nutrient availability and maize growth in a calcareous soil. *Soil Use and Management*, *33*(3), 447-456.

Salim, B. B. M. (2016). Influence of biochar and seaweed extract applications on growth, yield and mineral composition of wheat (*Triticum aestivum* L.) under sandy soil conditions. *Annals of Agricultural Sciences*, *61*(2), 257-265.

Shen, Y., Zhao, P., & Shao, Q. (2014). Porous silica and carbon derived materials from rice husk pyrolysis char. *Microporous and Mesoporous Materials*, *188*, 46-76.

Shende, G., Reddy, M. D., Pandey, G., & Kumar, A. (2020). Effect of different levels of nitrogen and phosphorus on performance of wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies*, *8*(2), 2019-2022.

Singh, H., Northup, B. K., Rice, C. W., & Prasad, P. V. (2022). Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis. *Biochar*, *4*(1), 1-17.

Singh, J., Sharma, H. L., & Singh, C. M. (2000). Effect of levels and phases of potassium application on growth and yield of rice and wheat. *Journal of Potassium Research*, *16*(1/4), 35-40.

Singh, R., & Agarwal, S. K. (2001). Analysis of growth and productivity of wheat (*Triticum aestivum* L.) in relation to levels of FYM and nitrogen. *Indian Journal of Plant Physiology (India)*.6(3), 279-283.

Sohi, S. P., Krull, E., Lopez-Capel, E., & Bol, R. (2010). A review of biochar and its use and function in soil. *Advances in agronomy*, *105*, 47-82.

Spokas, K. A., Cantrell, K. B., Novak, J. M., Archer, D. W., Ippolito, J. A., Collins, H. P., ... & Nichols, K. A. (2012). Biochar: a synthesis of its agronomic impact beyond carbon sequestration. *Journal of environmental quality*, *41*(4), 973-989.

Steel, R. G. D., & Torrie, J. H. (1980). *Principles and procedures of statistics, a biometrical approach* (No. Ed. 2). McGraw-Hill Kogakusha, Ltd..

Tasim, B., Masood, T., Shah, Z. A., Arif, M., Ullah, A., Miraj, G., & Samiullah, M. (2019). Quality Evaluation of Biochar Prepared from Different Agricultural Residues. *Sarhad Journal of Agriculture*, *35*(1), 134-143.

Wicks, L., & Firminger, H. (1942). Perchloric acid in micro-Kjeldahl digestions. *Industrial & Engineering Chemistry Analytical Edition*, *14*(9), 760-762.

Wu, W., Yang, M., Feng, Q., McGrouther, K., Wang, H., Lu, H., & Chen, Y. (2012). Chemical characterization of rice straw-derived biochar for soil amendment. *Biomass and bioenergy*, *47*, 268-276.

Xu, N., Tan, G., Wang, H., & Gai, X. (2016). Effect of biochar additions to soil on nitrogen leaching, microbial biomass and bacterial community structure. *European Journal of soil biology*, *74*, 1-8.

التأثيرات المستقلة والمشتركة للفحم الحيوي والأسمدة المعدنية على إنتاجية القمح وخصائص التربة

أيمن جمال عبدالراضى[1]، هدى محمد محمود المصرى[2] و محمد عيد عبدالحميد السيد[2]

[1] قسم بحوث القمح – معهد بحوث المحاصيل الحقلية – مركز البحوث الزراعية- الجيزة – مصر
[2] معهد بحوث الأراضي والمياه والبيئة - مركز البحوث الزراعية- الجيزة – مصر
بريد المؤلف المراسل ayman.gamal_1980@yahoo.com

أجريت هذه الدراسة خلال الموسمين الزراعيين 2019\2020 و2020\2021 بمحطة البحوث الزراعية بشندويل محافظة سوهاج لدراسة التأثير المفرد والمشترك لثلاث معدلات من الفحم الحيوي لقش الأرز وأربعة معدلات من الأسمدة المعدنية (النيتروجين والفسفور والبوتاسيوم) على الصفات المحصولية، محتويات النيتروجين والفسفور والبوتاسيوم في الأوراق والحبوب، محتوى البروتين والكربوهيدرات في الحبوب لصنف القمح مصر 3 وكذلك بعض خصائص التربة. كان التصميم التجريبي المستخدم هو القطع المنشقة مرة واحدة في ثلاث مكررات. تم وضع معاملات الفحم الحيوي في القطع الرئيسية بمعدل صفر، 5 طن و10 طن للهكتار بينما تم وضع الأسمدة المعدنية النيتروجين والفسفور والبوتاسيوم في القطع الثانوية بمعدل صفر و50 و75 و100% من المعدل الموصي به. أظهرت النتائج أن التطبيق المشترك لـ 10 طن للهكتار من الفحم الحيوي مع 100% من الأسمدة المعدنية النيتروجين والفسفور والبوتاسيوم سجل أعلى القيم للصفات المدروسة وكذلك حسن خصائص التربة مقارنة بالمعاملات الأخرى. علاوة على ذلك، أدى إضافة 10 طن للهكتار من الفحم الحيوي مع 75% و 100% من الأسمدة المعدنية النيتروجين والفسفور والبوتاسيوم إلى تحسين معنوي في محصول الحبوب بمعدل 11,13 و18,80% في الموسم الأول و 7,69 و 16,62% في الموسم الثاني على التوالي مقارنة بإضافة 100% من الأسمدة المعدنية النيتروجين والفسفور والبوتاسيوم بدون إضافة الفحم الحيوي . ختاما ،يمكن استخدام الفحم الحيوي لتقليل الاعتماد على الأسمدة الكيماوية (النيتروجين والفسفور والبوتاسيوم) بنسبة 25%.بالإضافة إلى تحسين خصوبة التربة وإنتاجية القمح.

الكلمات المفتاحية: بيوشار، الاسمدة المعدنية، جودة التربة، محصول القمح